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INSTRUMENTS FOR DETECTION AND IDENTIFICATION OF RADIOACTIVITY IN ENVIRONMENTAL MEDIA

Gerald J. Karches, et al

Robert A. Taft Sanitary Engineering Center
Cincinnati, Ohio

1960

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INSTRUMENTS FOR DETECTION AND IDENTIFICATION OF RADIOACTIVITY IN ENVIRONMENTAL MEDIA

A BROCHURE DESCRIBING THE INSTRUMENTATION AVAILABLE AT THE ROBERT A. TAFT SANITARY ENGINEERING CENTER, DIVISION OF RADIOLOGICAL HEALTH, FOR SURVEILLANCE OPERATIONS, RESEARCH, AND TRAINING.

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Radiological Health Research Activities

Details of illustrations in this document may be better studied on microfiche.

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
PUBLIC HEALTH SERVICE
Bureau of State Services
Division of Radiological Health

Robert A. Taft Sanitary Engineering Center
Cincinnati 26, Ohio

1960

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NOTE

This report is the second edition of a technical brochure originally issued as SEC Technical Report R59-3 under the same title.

The Robert A. Taft Sanitary Engineering Center is a national laboratory of the Public Health Service for research, training, and technical consultation in problems of water and waste treatment, milk and food safety, air pollution control, and radiological health. Its technical reports and papers are available without charge to professional users in government, education, and industry. Lists of publications in selected fields may be obtained on request to the Director, Robert A. Taft Sanitary Engineering Center, Public Health Service, Cincinnati 26, Ohio.

CONTENTS

	Page
Introduction	1
Counting Room	2
Internal Proportional Counters	2
Shielded Internal Proportional Converter	3
Geiger-Müller Counter in Lead Shield	3
End Window Geiger Counter, Automatic Sample Changer	4
Alpha Scintillation Counter	4
Large End Window Counter	5
Gross Gamma Counter	5
Low Background Beta (Anti-Coincidence) Counter	6
Gamma Pulse Height Analyzers	7
Four Pi Flow Counter	8
Low Level Spectrometer Systems	8
Liquid Scintillation Spectrometer	9
Beta Scintillation Counter	11
Automatic Air Sampler	11

FIGURES

Figure		
1	Overall view of counting room - second floor	2
2	Internal proportional counters for measurement of alpha, beta, and gamma activity	2
3	Shielded proportional converter	3
4	Geiger-Müller counter for measurement of beta-gamma activity	3
5	End window Geiger-Müller counter with automatic sample changer	4
6	Scintillation counter for measuring alpha activity	4
7	Large area end window proportional counter for measuring activity in air particulates	5
8	Gross gamma counter	5
9	Exterior view of low background anti-coincidence beta counter	6
10	Interior view of low background anti-coincidence beta counter showing sample chamber and anti-coincidence umbrella	6
11	100-channel pulse height analyzer with shield	7

FIGURES (Cont'd.)

Figure		Page
12	Transistorized 256 multi-channel analyzer with readout equipment	7
13	200-channel pulse height analyzer. Shield on left showing detector assembly	7
14	Four Pi flow counter for calibrating radioactive solutions	8
15	Interior view of steel shield showing 4" solid NaI (thallium activated) crystal and 5" photomultiplier tube assembly attached to door of steel shield	8
16	External well-type beaker which surrounds NaI crystal	9
17	Liquid scintillation spectrometer - exterior view	9
18	Liquid scintillation spectrometer - interior view showing sample chamber enclosed by 2" lead shield. The two photomultiplier tubes are at each end of the sample chamber	10
19	Beta scintillation counter	11
20	Automatic air sampler	11

INSTRUMENTS FOR DETECTION AND IDENTIFICATION OF RADIOACTIVITY IN ENVIRONMENTAL MEDIA

INTRODUCTION

This brochure describes and illustrates the variety of instruments available at the Center for measurement of radioactivity in various environmental media. Shown are instruments that may be used for the measurement of gross radioactivity; those for measuring specific kinds of radioactivity as from alpha, beta, or gamma emitters; and instruments such as the gamma spectrometer for identification of specific radionuclides.

The instrumentation described is located in two counting rooms, one used for surveillance counting, and the other for very low level and specific radionuclide counting. The surveillance counting room is equipped with the internal gas-flow proportional counters, and the two large area end window air sample counters. Two internal proportional gas-flow counters, a gross gamma counter, and a 20-channel pulse height analyzer are available for use by the research staff.

An expanded low level counting room was constructed for the housing of much of the specialized equipment, including four shielded internal proportional converters, the 100- and 200-channel pulse height analyzers and their shielded detectors, two low background beta (anti-coincidence) counters, and the liquid scintillation spectrometers.

The overall cost of equipment available to the Research Activities totals more than $135,000, purchased with regular funds from the Public Health Service and contract funds from the U.S. Atomic Energy Commission (Contracts No. AT-(49-5)-1288 and AT-(49-7)-1536).

Figure 1. Overall view of counting room - second floor.

COUNTING ROOM

Figure 1 shows an overall picture of the counting room on the second floor of the Sanitary Engineering Center. Regulated voltage for the room is provided by harmonic neutralized constant voltage transformers.* Along the left wall is a shielded Geiger tube and scaler, and two scalers associated with the 7-1/2" end window counters used for air sample counting. Internal proportional counters and converters, used for alpha and beta counting, are lined along the back wall. One of these counters is equipped with a lead shield to reduce background. The instrument on the right is a 20-channel analyzer used for gamma spectroscopy. The part of the "L"-shaped room not visible in the picture provides space for a work table and sample storage. A 5-ton air conditioner is located behind the cameraman and the entrance to the room is to the left just outside the picture.

*Sola Transformer Company, Chicago, Illinois

INTERNAL PROPORTIONAL COUNTERS

The internal proportional counters have many advantages for alpha and beta determinations. They offer high counting efficiency as a result of their 2π geometry, good reproducibility from sample to sample, and the ability to count either alpha or alpha plus beta-gamma activity by the proper selection of operating voltage. The sample chamber, shown in Figure 2, is 2-1/4" in diameter enabling 2" planchets to be used for samples. The large dishes minimize self-absorption losses.

The instrument has a background of less than 0.1 counts/minute in the alpha region and approximately 50 counts/minute in the beta region. The gas used for proportional counting is 90% argon, 10% methane, and is available commercially.*

The instrument can be purchased as a complete unit which has a 2500 volt power supply, preamplifier, timer, register, and scaler. A proportional counter converter is also available which includes the chamber and the preamplifier. This unit can be used with most scalers.

Figure 2. Internal proportional counters for measurement of alpha, beta, and gamma activity.

*The Matheson Co., Inc., East Rutherford, N.J.

SHIELDED INTERNAL PROPORTIONAL CONVERTER

Several of our proportional counters have 2" lead-shielded converters. This shielding reduces the background in the beta region from about 50 cpm for an unshielded converter to 20 to 30 cpm, depending on location. They are used for low activity samples, since their 2π counting geometry gives the high efficiencies desirable for counting such samples.

Figure 3 illustrates the counter and shows a sample being inserted in the shielded converter. The unit consists of a shielded chamber and preamplifier mounted in the same chassis. A 2500-volt power supply is required for the high voltage in the chamber, plus power for the preamplifier. Most commercially available scalers have the required power.

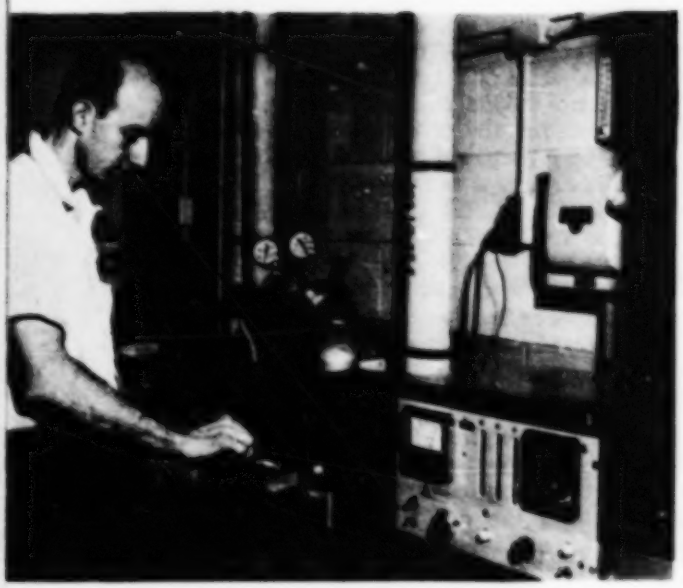


Figure 3. Shielded proportional converter.

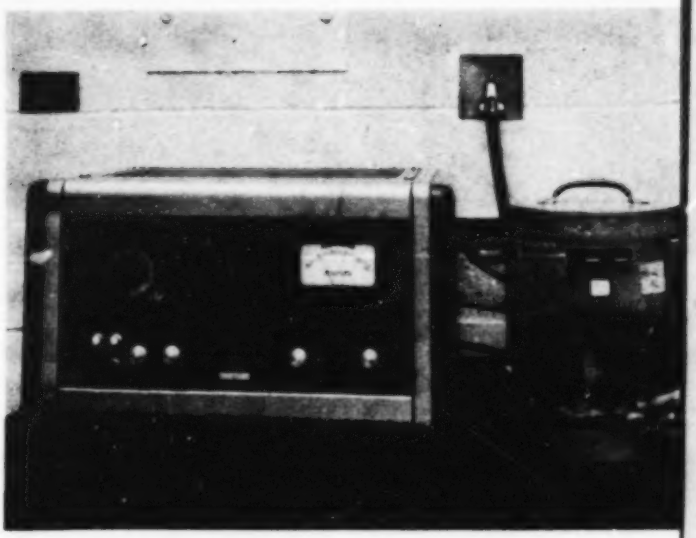


Figure 4. Geiger-Müller counter for measurement of beta-gamma activity.

GEIGER-MÜLLER COUNTER IN LEAD SHIELD

The Geiger-Müller counter finds limited use for most environmental samples. It is extremely energy dependent, especially at low energies, because the air path between the sample and the window, and the window itself, stops many of the weak betas. Reproducibility from sample to sample is poor because the efficiency of detection varies with position of the activity in the dish.

The G-M detector finds its biggest use for tracer studies. It does not require elaborate sample preparation because the sample is external to the detector. A tube of this type can be used to determine beta energies by placing absorbers between the sample and the detector. As shown in Figure 4 the detector is housed in a lead shield to reduce background to approximately 30 cpm for the 1-1/4" diameter tube used.

A scaler having a high voltage of 1500 volts is adequate for the G-M counter. The pulses are carried on the same cable as the high voltage and no preamplifier is necessary. This detector is relatively cheap and simple as far as the electronics are concerned.

END WINDOW GEIGER COUNTER, AUTOMATIC SAMPLE CHANGER

This counter (Figure 5) has the capacity of counting 24 samples consecutively, repeating the procedure until stopped. Background levels have been constant at 15 or 16 cpm. Counts can be controlled according to time or total counts. The results are recorded on a readout tape as the total count in a given interval of time or as the time interval required to register a predetermined number of counts.

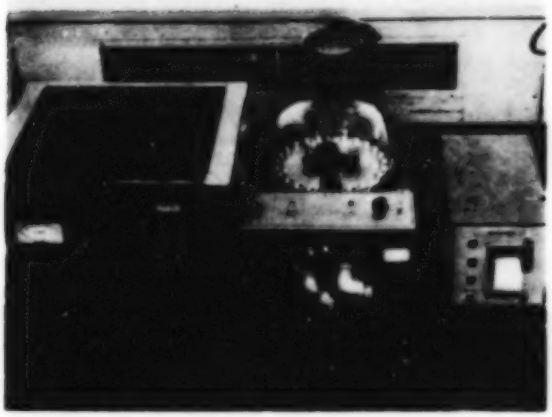


Figure 5. End window Geiger-Müller counter with automatic sample changer.

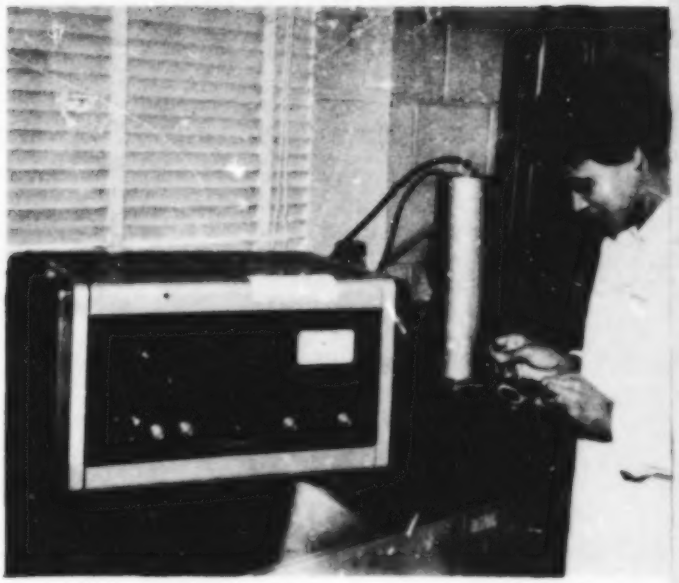


Figure 6. Scintillation counter for measuring alpha activity.

ALPHA SCINTILLATION COUNTER

Depending on the phosphor employed, alpha, beta, or gamma activity may be counted in this instrument (Figure 6). It is currently being used as an alpha counter with a zinc sulfide screen and a 6292 Dumont photomultiplier tube. As shown in the illustration, the sample is placed on a platform which screws into the base for adjustment of sample height. It is connected to a scaler having at least 2000 volts power supply. The power requirements for the pre-amplifier in the counter are: 6.3 volts A.C. for the filament, and 75 to 180 volts at about 5 milliamperes for the plate. Most scalers have these power requirements.

The scintillation counter is very sensitive to alpha particles and requires no special sample preparation as is the case with the internal proportional counter. It is used for determining the radon daughter product activities in air samples and has an optimum geometry of around 45 per cent. Background levels for alpha counting amount to less than 0.3 cpm. The counting efficiency for alpha detection is about 40 per cent as compared to 50 per cent in the internal counters.

LARGE END WINDOW COUNTER

Two end window proportional counters 7-1/2" in diameter are used to count the large filter samples collected by the National Air Sampling Network. The filters, having an active area 7" by 9", are placed directly under the thin Mylar window as shown in Figure 7. The chamber is equipped with seven wire loops for the high voltage, and P-10 gas (90% argon, 10% methane) is used for flushing.

Although primarily for gross beta-gamma counting of deposited air particulate activity, the counter has been used for other samples having a high solid content. Self-absorption losses in such samples can be minimized by spreading over a larger area. Loosely held solids, milk powder for instance, can also be counted since the sample is external to the flow of gas. The background is about 500 cpm with no shielding.

The converter (a jointly mounted chamber and preamplifier) is connected to a scaler having a high-voltage supply of at least 2500 volts and appropriate voltages to power the preamplifier (6.3 volts A.C. at 1.5 amps; 250 to 300 volts D.C. at 20 ma; 150 to 200 volts D.C. regulated at 8 ma). Most commercially available scalers have these voltages.

Figure 7. Large area end window proportional counter for measuring activity in air particulates.

Figure 8. Gross gamma counter.

GROSS GAMMA COUNTER

A gross gamma counter shown in Figure 8 utilizes either a 2" solid or well sodium iodide crystal. The shield consists of 1-3/4" of lead and 1/4" of steel which lowers the background to about 250 cpm. Since it couples through a cathode follower directly into a scaler, the system is quite simple and relatively inexpensive. A counter of this type is useful for tracer levels and for determining the recovery factor of a radiochemical technique.

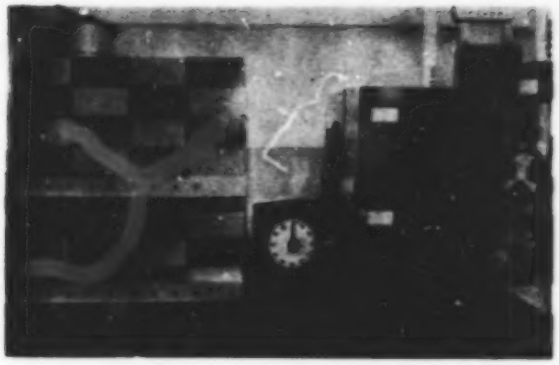


Figure 9. Exterior view of low background anti-coincidence beta counter.

LOW BACKGROUND BETA (ANTI-COINCIDENCE) COUNTER

The low background beta (anti-coincidence) counter has two very thin window (0.9 mg/cm^2) Geiger tubes as the central counters. These require a continuous flow because of gas diffusion through the very thin windows. This counter is designed for counting samples which are very low in activity, as low as one disintegration per minute. A counting time of 100 minutes is usually required to obtain reasonable statistics.

The low background of 0.7 counts per minute is achieved by 2-1/2 tons of steel (see Figure 9) and a cosmic ray umbrella of 11 Geiger tubes in a semi-cylindrical arrangement over the central counters. When a cosmic ray passes through the umbrella it cannot be recorded as an event in the central counter but is electronically eliminated as a potential count. The gamma rays present in the air are stopped by the steel which surrounds the entire counter system.

Figure 10. Interior view of low background anti-coincidence beta counter showing sample chamber and anti-coincidence umbrella.

The central counters, shown in Figure 10, have 2" diameter window openings and are separated by a 1" wall of mercury to minimize "cross talk" between the detectors. Each tube has its own scaler, as does the umbrella ring on top.

By placing 2" planchets as close to the window as practicable, the counting efficiency for yttrium-90 spread over the entire dish is 42 per cent. The combination of low background and high efficiency makes an instrument of this type a most useful low level beta counter.

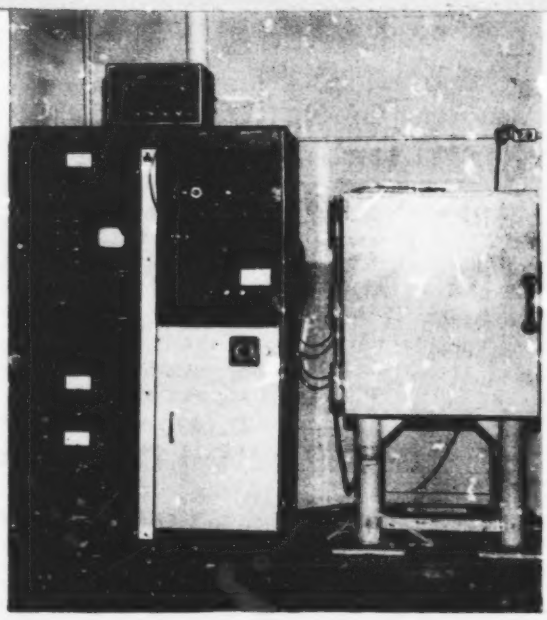


Figure 11. 100-channel pulse height analyzer with shield.

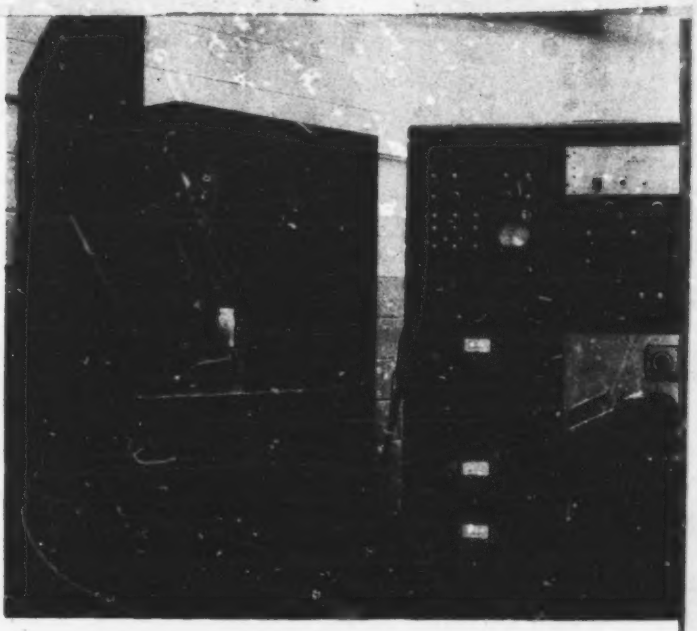


Figure 13. 200-channel pulse height analyzer. Shield on left showing detector assembly.

GAMMA PULSE HEIGHT ANALYZERS

The basis for gamma spectrometry is the emission of gamma photons in a characteristic line spectrum consisting of a few discrete energies. The utilization of these spectra for the identification of specific radionuclides requires detectors capable of an output proportional to the gamma energy.

Almost all gamma spectroscopy systems now use a thallium activated sodium iodide crystal, a photomultiplier tube, and a linear amplifier to produce a pulse proportional to the gamma energy. The resulting pulses are then usually fed into a unit which either (1) responds to all pulses larger than a preset value (integral discriminator), (2) responds to all pulses between two preset values (single channel analyzer), or (3) sorts pulses into a number of channels depending on their size (multichannel analyzer).

Gamma spectroscopy offers a means of simplifying the identification of specific radionuclides. Furthermore, because gamma radiation is absorbed to only a very minor degree, this technique permits the utilization of large samples with much less stringent sample preparation techniques than are required for alpha and beta counting. Gamma measurements appear to be somewhat less sensitive than alpha or beta measurements, and there is some interference of one gamma radiation with another in complex mixtures.

Although only multichannel analyzers are shown (Figures 11, 12 and 13), it is possible to use a single channel analyzer to obtain the same information if the levels of activity are high enough. For most environmental samples a multichannel unit is needed because long counting times are required.

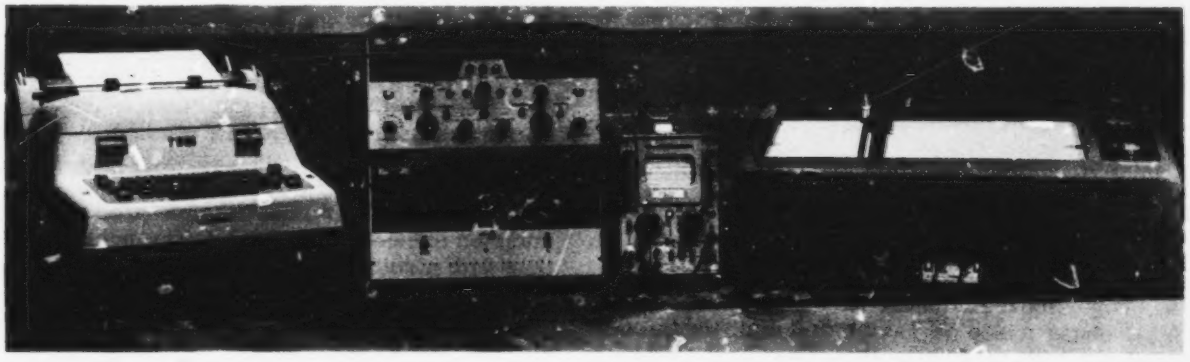


Figure 12. Transistorized 256 multi-channel analyzer with readout equipment.

4π FLOW COUNTER

The 4π counter (Figure 14) is employed for the absolute standardization of solutions used to calibrate other instruments. It is most useful in standardizing nuclides which have a large variety of beta energies because backscatter corrections are not necessary and the counting efficiency approaches 100 per cent for all beta energies. These isotopes cannot be standardized accurately in a 2π counter, especially when the relative abundances of the different betas are unknown. Sample preparation is very exacting, requiring the source to be essentially weightless and to be mounted on a very thin ($\mu g/cm^2$) conducting film.

A high voltage center wire with separate leads is provided for each chamber. It is therefore possible to count from each chamber separately, enabling corrections to be made for absorption losses through the very thin mounting film.

The counter operates in either the Geiger region or the proportional region, depending on the gas used. Methane is commonly used because the plateaus are over 500 volts long. Since there are three plateaus to be concerned

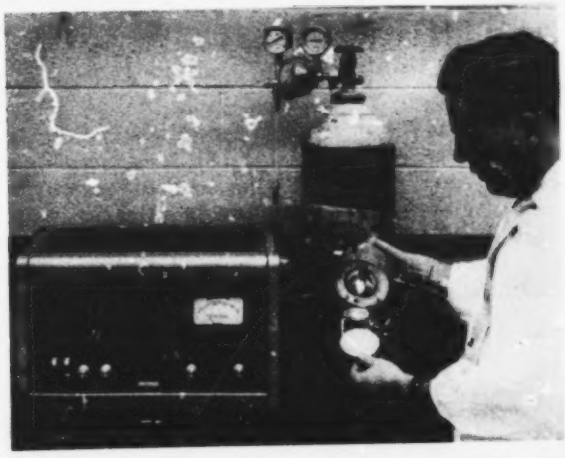


Figure 14. Four Pi flow counter for calibrating radioactive solutions.

with, top, bottom, and both chambers together, it is necessary to have overlap. The operating voltage for this gas is about 4000 volts.

An amplifier is required when operating in the proportional region. It is therefore advisable to purchase a scaler having an amplifier built in along with a 5000-volt power supply. All other power requirements are usually met by most scalers.

LOW LEVEL SPECTROMETER SYSTEMS

(1) The four-ton, six-inch steel shield, shown in Figure 11, is located in the low level counting room. It was laminated of one-inch steel plate. Before use, the steel plate had to be sandblasted to remove surface contamination from fallout. Outside dimensions of the shield are 30" x 30" x 36", inside dimensions 18" x 18" x 24". It is supported on 4" steel pipes. The door, weighing approximately one ton, is supported by three large hinges and swings quite freely.

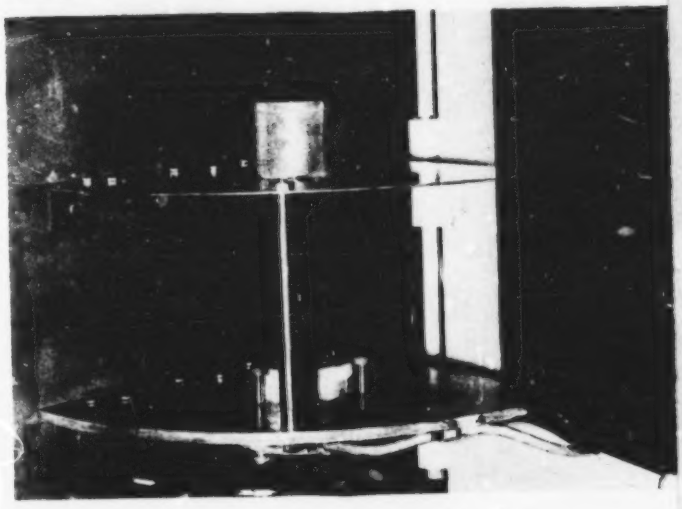


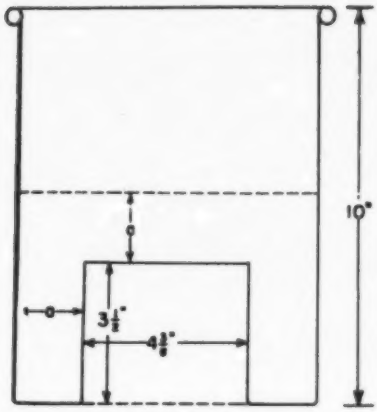
Figure 15. Interior view of steel shield showing 4" solid NaI (Thallium activated) crystal and 5" photomultiplier tube assembly attached to door of steel shield.

A 4" x 4" NaI (Tl activated) crystal and 5" photomultiplier tube are attached to the inside face of the door. Background is comparable to a 2" x 2" solid NaI crystal with 1-3/4" of lead shielding and is about 480 cpm over a 0 to 2 Mev range.

The interior view of the shield is shown in Figure 15. The 4" x 4" solid sodium iodide (thallium activated) crystal is coupled to a 5" Dumont #6364 phototube. Because of its size, the full energy of high energy gammas may be captured, thus extending the range of operation of our gamma spectrometers. Furthermore, the efficiency of detection of gamma radiations of less than 2 Mev (which covers most of the radiations from mixed fission products and common induced activities) is very much greater than with a common 2" x 2" crystal.

Specially designed beakers shown in Figure 16 surround the crystal to give optimum geometry for liquid samples up to 3.5 liters in volume. Smaller liquid samples and solid

GPO 807065-2



VOLUME	a
1 l.	2¼"
2 l.	1⅝"
3.5 l.	1⅜"

Figure 16. External well-type beaker which surrounds NaI crystal.

samples may be counted by placing them directly on top of the crystal.

(2) A new shield and large crystal combination is shown in Figure 13. Much of the construction is patterned after the original shield shown in Figure 11, but an inner lining of lead covered with steel has been added to reduce backscatter and the low-energy background.

The crystal assembly is a 4" x 4" solid sodium iodide (Tl activated) crystal optically coupled to a de-based 3" Dumont #6363 photomultiplier tube. As in the initial 4" crystal, the window on the new crystal is also of quartz. The entire assembly, purchased as a package deal, includes the crystal, photomultiplier, cathode follower, and mu metal shield around the tube. To insure good resolution, which incidentally is less than 8 per cent, a 3"-tube is used.

The inside dimensions of the shield are 24" x 24" x 36", and the total weight is greater than five tons. The background is about 250 cpm over a 0 to 2 Mev range which essentially is half the value obtained with the old shield and 4" crystal. The lower background was achieved by the following modifications: (1) removal of the phototube base assembly, (2) use of a smaller photomultiplier tube window which has less potassium, (3) lower potassium content in the crystal, and (4) a liner of lead for additional shielding.

LIQUID SCINTILLATION SPECTROMETER

The liquid scintillation spectrometer is used for counting very weak beta particles, especially tritium and carbon-14. Beta particles associated with these isotopes have very low energies and therefore are difficult to count by ordinary means.

The unit employed at the Center consists of a light-tight, optical sampling chamber with convenient shutter mechanism and two photomultipliers shielded by two inches of lead in all directions and placed in a 13 cubic-foot freezer chest.

Figure 17 shows the complete assembly with the analyzer at the left and the freezer chest at the right. The detector assembly is shown in Figure 18. The two photomultiplier tubes are at each end of the assembly, and the sample is placed in the central sample container and covered with the hinged shield flap. The sample container is completely housed in a 2"-lead shield.

By having two photomultipliers "look at" the sample bottle containing the solution of radioactive sample and liquid scintillator, legitimate light pulses are seen simultaneously by both. An electronic coincidence circuit is provided to pass such pulses and to reject thermionic noise pulses which occur at random in the two photomultipliers and only very rarely chance to coincide in time. There are practically no

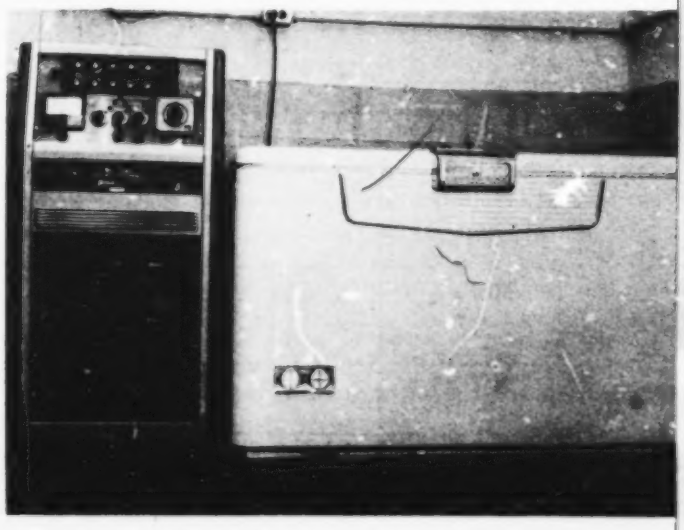


Figure 17. Liquid scintillation spectrometer – exterior view.

counts contributed to the background from this source (2 or 3 cpm). This type of background must be sharply differentiated from "true" background due to cosmic rays and local extended gamma radiation.

The background on the instrument varies depending on the scintillating solution, voltage tap, etc. Some background values obtained under varying conditions are tabulated below.

The idea of liquid scintillation counting is simply to put the sample in solution with a liquid scintillator, thus giving essentially 100 per cent geometry and no self-absorption. Dilute solutions of fluorescent substances in aromatic solvents are useful as scintillation detectors.

The efficiency of detection varies as a function of the solvents used. Tritium in a solution of toluene yields an efficiency of about 18 per cent and carbon-14 in the same solvent, about 70 per cent.

If the energies of two radionuclides differ by a factor of at least six, the unit may be used to differentiate between them. Thus, it is possible to count tritium (maximum energy 0.018 Mev) and carbon-14 (maximum energy 0.115 Mev) and to record the respective counts in separate channels. When used in this manner, the unit is referred to as a two-channel analyzer.

The analyzer is installed in a room without fluorescent light. This is important since fluorescent light activates the potassium in glass, thus appreciably increasing the background. After exposure to fluorescent light, the sample must be stored in the dark for at least 8 hours before the activated potassium dies out. The use of incandescent light avoids this difficulty.

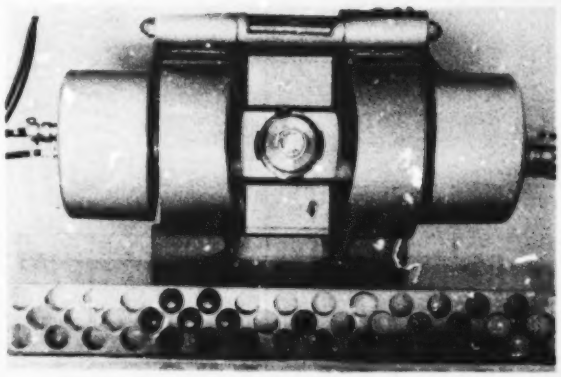


Figure 18. Liquid scintillation spectrometer – interior view showing sample chamber enclosed by 2" lead shield. The two photomultiplier tubes are at each end of the sample chamber.

The complete assembly of analyzer, freezer, and detector comes as a packaged unit and is ready for use without additional equipment. Although this unit is designed primarily for weak betas, it can be used for alpha counting and also for higher energy betas, especially for spectroscopy.

High voltage tap	Background, cpm*			Remarks
	10 to 50	10 to 100	10 to ∞	
H V 9		50.1±0.4**	98.5±0.6	"611" solution (6 pt. dioxane, 1 pt. anisole, 1 pt. dimethoxyethane) plus 20% water. PPO and POPOP added.
H V 9		43.8±0.4	88.1±0.6	Bell's solution (10 pt. dioxane, 0.5 pt. naphthalene) plus 10% water. PPO and POPOP added.
H V 9		109.0±0.6	166.8±0.8	From Packard Instrument Company.
H V 7	15.3±0.2	21.6±0.2		Tri-Carb (shutter open, sample chamber empty).
H V 7	44.1±0.4	53.8±0.4		Tri-Carb (empty vial).

* At discriminator settings indicated.
** ± 2σ (counting error).

BETA SCINTILLATION COUNTER

The beta scintillation counter shown in Figure 19 can be used both as a gross beta counter and as a spectrometer, depending on the associated readout equipment. The entire shield was designed and built at the Center specifically for beta scintillation counting.

The shield consists of 1-1/4 inches of lead and 1/2 inch of steel. The inside diameter is 4 inches and the height is 17-1/2 inches. It can be disassembled into three sections, which simplifies trouble shooting of the electronics, and facilitates moving the shield.

A cathode follower is required along with an amplifier because pulses from a plastic phosphor are relatively small. A discriminator and a high voltage supply of 2000 v are also necessary and are commercially available in scalers and analyzers.

The background for a 2" x 1/16" plastic phosphor is less than 20 cpm when used as a gross beta counter. The efficiency of detection for a U_3O_8 2" diameter source mounted as close to the detector as possible is about 50 per cent of the counting rate in an internal counter. A thicker crystal will yield a slightly higher efficiency than the 1/16" detector, but a higher background will result. Only preliminary spectroscopy work has been started and information on this aspect is not now available.

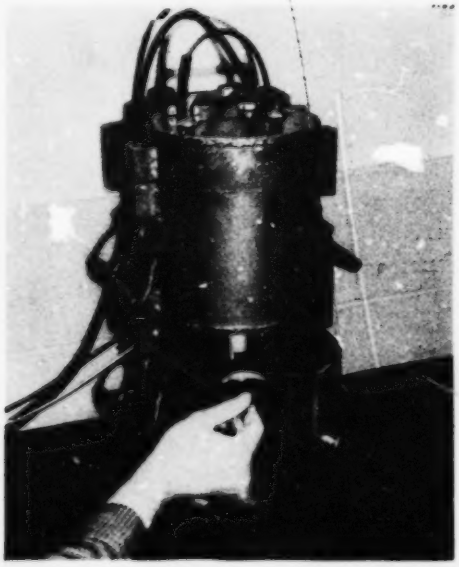


Figure 19. Beta scintillation counter.

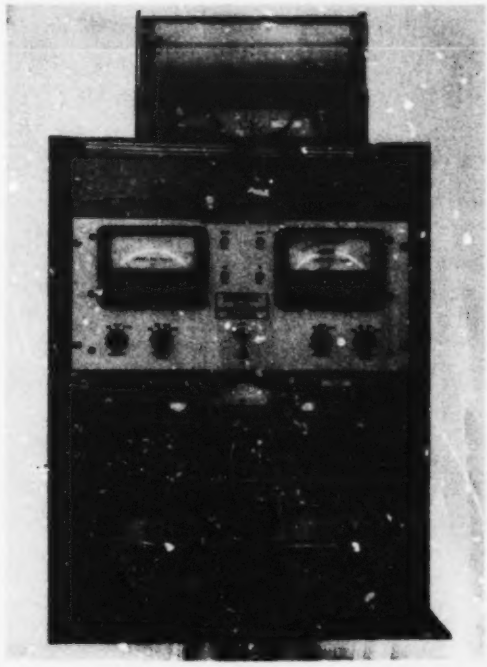


Figure 20. Automatic air sampler.

AUTOMATIC AIR SAMPLER

The automatic air sampler (Figure 20) collects the airborne activity on a 1 inch wide membrane tape filter in a stepwise movement. The collection time is determined by a 0 to 24 hour timer. An air flow of 0 to 2 cfm through a filter area of 4.5 cm^2 is supplied by a rotary vane pump.

Two ZnS(Ag) alpha scintillation detectors monitor the sample for natural activity levels. The signal is then supplied to a dual-channel 3-cycle logarithmetic ratemeter, detector 1 having a range of 50 to 50,000 cpm and detector 2 a range of 5 to 5,000 cpm. Greater sensitivity is required on the second counter because this detector counts the sample after the radon daughters have decayed, leaving thoron daughters only which are usually down by a factor of 10. The output from the rate meters is recorded on a dual-channel strip-chart recorder.